BASIC STUDY ON TRAJECTORIES OF REACHING MOVEMENTS IN CHILDREN WITH LEARNING DISABILITIES

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Abstract — **A number of children with learning disabilities (LD) are not good at visuomotor control. In this study, we analyzed hand trajectories and joint angles during reaching movement tasks under rotated visual feedback in subjects with and without LD. The error in ballistic movement was determined by measuring the angle between the direction in which the subject started to reach out and the direction of the target (error angle), and the error in corrective movement was determined by the measuring the area between the trajectory and a straight line drawn between the starting point and the end point (error area). In the initial movement when the visual field had been rotated 30 deg, error angles were about –30 deg in both the LD and normal groups; however, the error area was 2.9 cm^2 greater in the LD group than in the normal group. On the other hand, joint paths of the shoulder in reaching the same target tended to change in the LD group. These results suggested that the LD subjects had worse skills in corrective movement than did the normal subjects and that adaptation by the LD subjects occurred more slowly than that by the normal subjects.**
Keywords — **Vision, Proprioception, Adaptation, Reaching, Learning disabilities**

I. INTRODUCTION

Reaching to visual targets requires a complex transformation from the visual representation of the target to the required motor output, as well as integration of the resultant proprioceptive and visual information concerning the outcome of the movement. Prism adaptation experiments have shown that these transformations are flexible [1]. Accurate reaching toward a visual target is disturbed when the visual field is displaced by prisms but recovers with practice. After the prisms have been removed, errors in the direction opposite to the prism displacement are observed (aftereffect). How trajectories of reaching are planned, where prism adaptation occurs, and what kind of information on the movement is used for adaptation are still unclear. Imamizu and Simojo [2] reported that the locus of visual-motor learning under rotated visual feedback should be at the task level (determination of the trajectory of a hand during arm reaching in Cartesian coordinates) rather than at the manipulator level (determination of the joint coordinates). It was found that reaching movements are not planned in Cartesian space but in visually perceived space [3], [4]. However, Sergio and Scott [5] reported that blind people, even those who had been deprived of visual feedback very early in life, made a fairly straight hand trajectory.

On the other hand, some children with learning disabilities (LD) are not good at visuomotor control. It is likely that such children have problems in sensory integration of vision and proprioception.

In this study, we analyzed hand trajectories and joint angles during reaching tasks under rotated visual feedback in subjects with and without LD, and errors and aftereffects were determined and compared. Each reaching movement has two components: an “initial impulse” and a series of “secondary adjustments” made subsequently to attain the final target position [6]. The first component has been named “ballistic” movement, and the second component has been named “corrective” movement [7]. We focused on error direction in the ballistic movement of reaching.

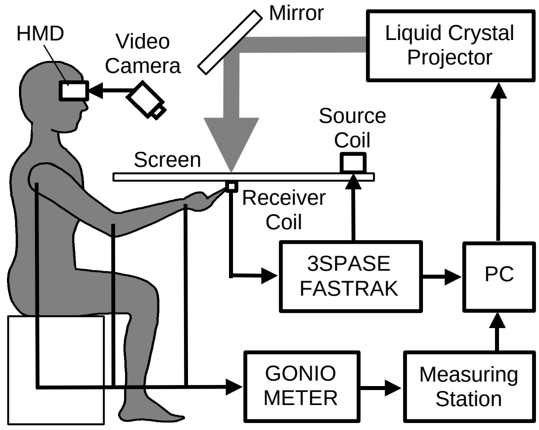

Fig. 1. Schematic diagram of the experimental setup.

II. MATERIALS AND METHODS

A. Subjects

Two normal adults (males, aged 18 and 24 years) and two children with LD (males, both aged 13 years) participated in the experiments. All participants expect for one child with LD (TS) were right-handed. All subjects were unaware of the purpose of the experiments.

B. Apparatus

A schematic of the experimental setup is shown in Figure 1. Each subject was seated in front of a horizontal screen (6 mm thick) placed at chest height, with his head restrained by a chin rest. Each subject also wore a head-mounted display (HMD) (PLM-S700, Sony) connected to a video camera (CCD-MC100, Sony). Visual targets and a cursor created by a computer (Millennia, Micron) were projected onto the screen by a liquid crystal display (LCD) projector (ELP-3500, Epson). These visual images on the screen were displayed on the HMD through the video camera.

Each subject moved his finger on the underside surface of the screen. The trajectories of the hand were monitored by magnetic sensors (3SPACE FASTRAK, Polhemus; accuracy, 0.8 mm), and a receiver coil was placed on the subject’s index finger. Joint angles of shoulder, elbow and wrist were also monitored by a goniometer (Penny and Giles) and a

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25OCT2001	N/A	-

Title and Subtitle Basic Study on Trajectories of Reaching Movements in Children with Learning Disabilities	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Division of Biomedical Systems Engineering, Graduate School of Engineering, Hokkaido University, Sapporo, Japan	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 4	

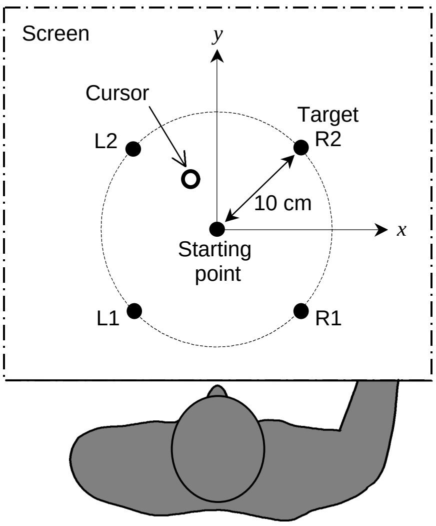

Fig. 2. Locations of the visual targets.

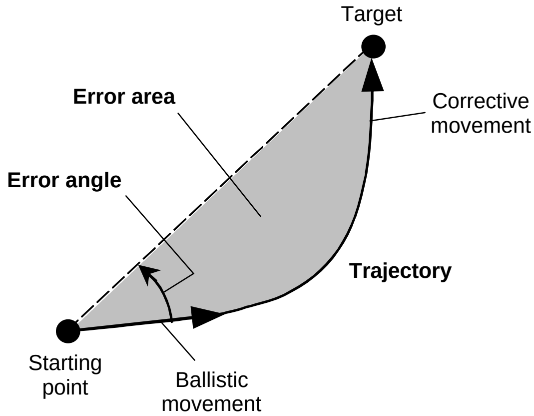

Fig. 3. Definitions of error angle and error area.

TABLE I
CHARACTERISTICS OF THE EXPERIMENTAL SESSIONS.

Session	Hand	Target
RR	Right	R1
LL	Left	L1
RL	Right	L2
LR	Left	R2

measuring station (WE-400, Yokogawa). The positional and joint data obtained during the task movements were stored on a computer.

Except for the exposure period, the visual cursor on the screen represented the position of the fingertip under the screen in real time. Therefore, the subject could move the feedback cursor using his own index finger. In the exposure period, the cursor's position was rotated counterclockwise by 30 deg in the center of the starting point.

C. Procedure

Each experimental session consisted of 30 trials, and each subject performed 4 sessions (total of 120 trials). Figure 2 shows the locations of the visual targets. The starting point and the cursor were illuminated throughout the period of the experiment. In each session, one of the 4 targets was used repeatedly.

Each trial consisted of the following sequence. The target appeared when the subject pointed to the starting point from the underside of the screen, or, more precisely, moved the cursor to the starting point. The target remained there until the cursor arrived at it. The subjects were instructed to make their paths from the starting point to the target as straight as possible, and the positional data were stored on a compute.

For the first 10 trials (pre-exposure period), the position of the feedback cursor represented that of the fingertip correctly. Thus, the subjects were able to perform reaching movements as well as they could under normal conditions. For the next 10 trials (exposure period), the visual feedback was altered. Accurate reaching was disturbed but recovered with practice. For the final 10 trials (post-exposure period), the position of the feedback cursor represented that of the fingertip correctly again and the subjects misreached in the directions opposite to the exposure movements (aftereffect).

The session in which the subject moved his “right hand” to “target R1” (Fig. 2) was named session RR. Similarly, session RL was right hand and target L2, session LL was left hand and target L1, and session LR was left hand and target R2 (see Table 1). In session RR and session LL, each subject used one hand in the same side of the space. In session RL and session LR, on the other hand, each subject's hand crossed his body midline.

D. Data analysis

The positional data of the hand from the starting point to the target were stored in a computer and analyzed. The trajectories of reaching movements were curved during the exposure and post-exposure periods (see Fig. 3). The curvatures of all trajectories were measured in 2 ways: (1) error angle and (2) error area.

Error angle is the angle between the direction in which the subject started to reach out and the direction of the target. Error angle is thus the direction in which the subject estimated that the goal target was situated. This angle reflects ballistic movement of reaching.

Error area is the area between the trajectory and a straight line drawn between the starting point and end point. If the subject corrects his hand path earlier, the error area becomes smaller. This area reflects not only ballistic movement but also corrective movement.

Joint angles of shoulder adduction, shoulder flexion, elbow flexion and wrist flexion were measured during reaching tasks, and coordination among joints was examined.

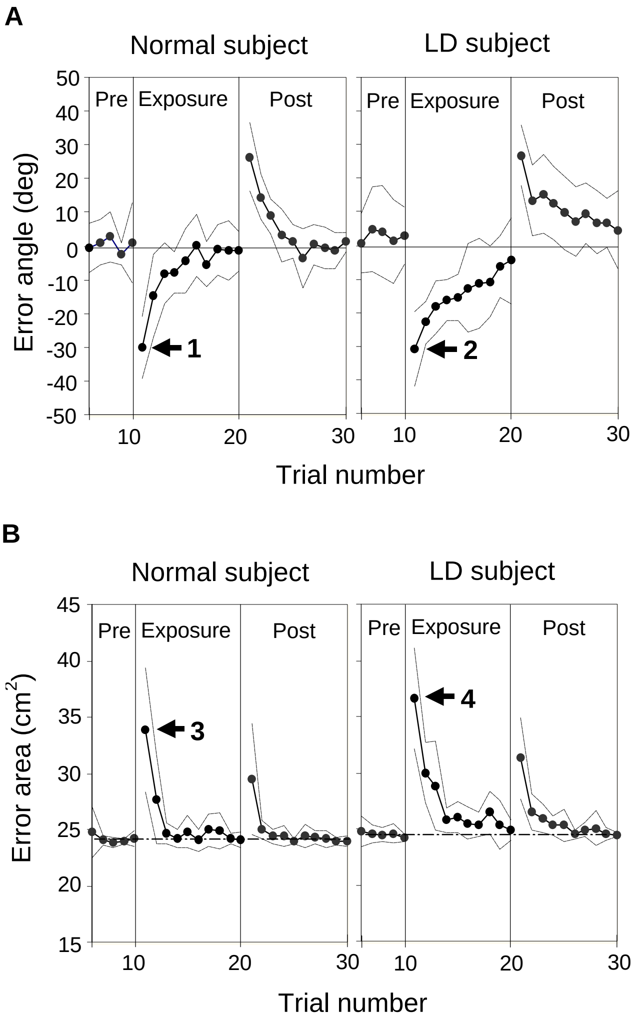

Fig. 4. Mean error angles (*A*) and mean error areas (*B*) in the normal and LD subjects.

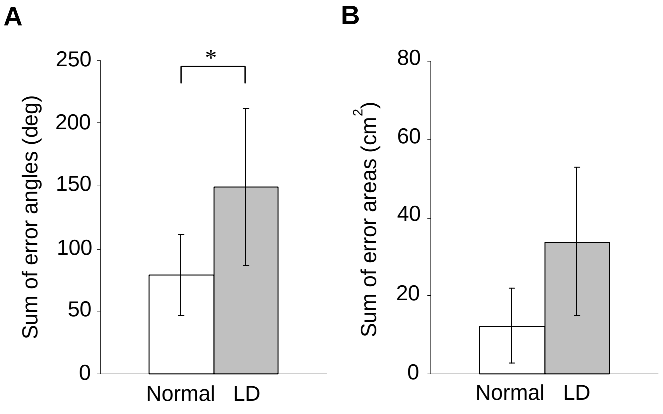

Fig. 5. Sum of error angles (*A*) and sum of error areas (*B*) (trials 11–20). $*p < 0.05$

III. RESULTS

A. Error angles and error areas

In the pre-exposure period (trial 10), the subject's hand followed a fairly straight path. In the first exposure movement (trial 11), the trajectory deviated from the straight lines drawn between the end points, and accurate reaching was achieved after practice (trial 20). In the post-exposure period, however, hand paths were curved in the direction opposite to the exposure movements.

Figure 4 shows mean error angles and mean error areas in normal and LD subjects. Error angles reflect the ballistic movement of reaching. On the other hand, error areas are the results of both ballistic and corrective movements. In the pre-exposure period, error angles were around zero, and error areas were almost the same. The baseline (control level) was defined as the mean error area of the final 5 pre-exposure movements (trials 6–10). Baselines were 24.2 cm^2 in the normal subjects and 24.5 cm^2 in the LD subjects. In the initial exposure trial (trial 11), mean error angles were around –30 deg in both groups, –30.0 deg in normal subjects (epoch 1) and –30.9 deg in LD subjects (epoch 2), as a result of 30 deg rotations of visual cursors; however, the mean error area was higher in the LD subjects than in the normal subjects (epochs 3 and 4). The difference is attributed to the skill of corrective movements.

During the exposure period, errors decreased to near zero or baselines. The errors made by the normal subjects decreased more rapidly than those made by the LD subjects. Interestingly, the difference in error angles was clearer than that in error areas. The sum of error angles and the sum of error areas in the exposure period (trials 11–20) are shown in Figure 5. These indicate the degrees of adaptation to changed feedback. The sum of errors was higher in the LD subjects than in the normal subjects. The sums of error angles in the two groups were significantly ($p < 0.05$) different.

In the post-exposure period, aftereffects appeared in error angles and error areas (see Fig. 4), and then errors decreased again.

B. Joint angles

Four kinds of joint angles (shoulder adduction, shoulder flexion, elbow flexion and wrist flexion) were measured during reaching tasks. The wrist joint was used only a little, and there were no noticeable differences in wrist joint movement between sessions or between subject groups. The wrist may be used for fine turning of reaching movement. Figure 6 shows typical relationships between elbow flexion and shoulder flexion and between elbow flexion and shoulder adduction. These relationships were similar in both the LD and normal groups. Both trials 8–10 and trials 28–30 involved the same movements under the same conditions, having no rotation of the visual field. Hand trajectories in these trials were fairly straight in both the LD and normal groups. In the LD group, however, there were clear differences in the use of the shoulders in trials 8–10 and in trials 28–30. In this study, the subjects' heads were restrained, but their shoulders were not restrained in order for the

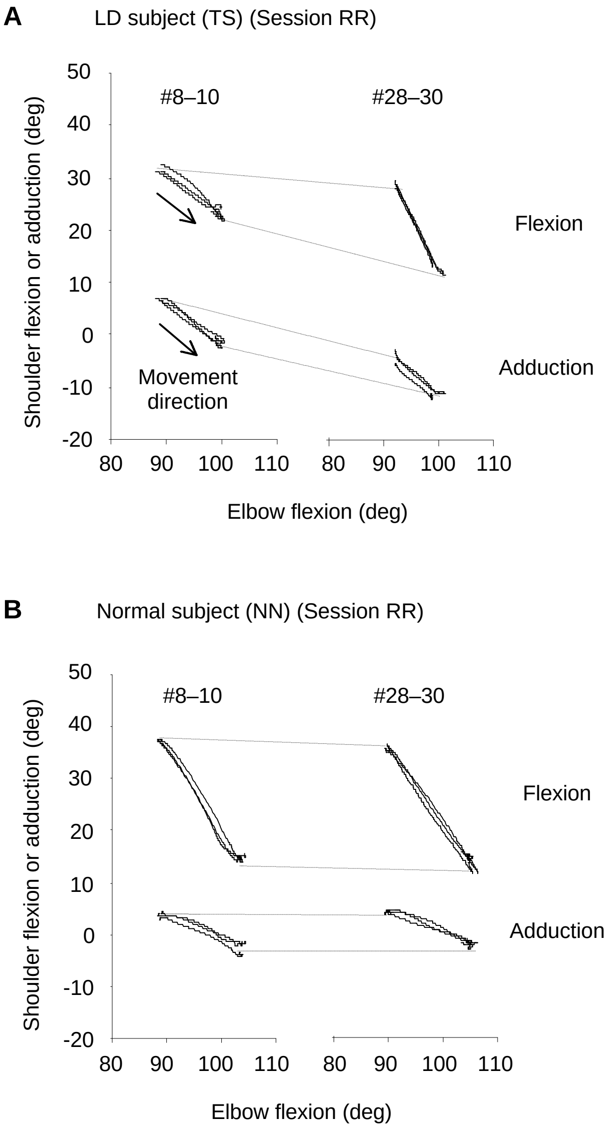

Fig. 6. Typical relations of joint angles of shoulder and elbow.

subjects to be able to perform reaching movements naturally. On the other hand, shoulders angles of subjects in the normal group in trials 8–10 and in trials 28–30 were very similar.

IV. Discussion

In the present study, we measured the trajectories of reaching movements to visual targets by subjects with and without LD, and we analyzed errors in the exposure period (under rotated visual feedback) and aftereffects in the post-exposure period. The error in ballistic movement was determined by measuring the angle between the direction in which the subject had started to reach and that of the target (called error angle), and the error in corrective movement was determined by measuring the area between the trajectory and a straight line drawn between the starting point and end point (called error area).

In the pre-exposure period, error angles and error areas were around the baselines (control levels) in both groups. In the initial exposure movement (trial 11, Fig. 4, epoch 3), the only difference between the LD and normal subjects was in the error area. These results suggested that the LD subjects were not as good at corrective movement as the normal subjects. The LD subjects could plan the trajectories (for example, at CNS) as well as the normal subjects but could not rapidly correct the hand path using visual and proprioceptive information.

In the exposure period, error angles in the movements by LD subjects decreased less rapidly than those in the normal subjects. It is likely that adaptation by the LD subjects occurred more slowly than that by the normal subjects. A possible reason for this is that the planning of trajectories by the LD subjects (for example, the internal space model) was less flexible.

In the LD group, there were clear differences in the use of the shoulders in trials 8–10 and in trials 28–30, indicating that children with LD do not tend to choose only one joint path for the same hand path. If adaptation occurs at the manipulator level (determination of the joint coordinates), these indefinite coordinates among joints may cause worse adaptation. According to Clower [8], the use of actual feedback of the hand during exposure to prisms caused a greater aftereffect than did the use of computer-generated representation feedback of the hand's position. In the present study, we used visual feedback represented by computer graphics, and it is possible that the aftereffect was smaller than that in real space. The aftereffects in the movements without crossing were greater in the LD subjects than in the normal subjects, suggesting that the LD subjects adapted by using perceptual recalibration rather than visuomotor skill acquisition.

Acknowledgment

The research was partially supported by a research grant from the Ministry of Education, Culture, Sports, Science, and Technology, Japan (10558015).

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